

# COMPARISON OF US BLAST DESIGN GUIDANCE DOCUMENTS

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## Abstract

For many years, the US Department of Defense has maintained two primary blast design manuals, UFC 3-340-01 (formerly Army TM 5-855-1/Air Force AFPAM 32-1147(I)/Navy NAVFAC P-1080/DSWA DAHSCWEMAN-97), "Design and Analysis of Hardened Structures to Conventional Weapons Effects" and UFC 3-340-02 (formerly Army TM 5-1300/Navy NAVFAC P-397/Air Force AFR 88-22), "Structures to Resist the Effects of Accidental Explosives." More recently, the American Society of Civil Engineers has established a technical committee to develop a new blast design standard for antiterrorism applications, based largely upon criteria and guidance issued by the US Army Corps of Engineers Protective Design Center. In this paper, we will investigate the scope and application of these blast guidance documents. Particular attention will be paid to each manual's performance and design objectives as implemented through their respective protection categories and resulting structural design requirements.

## Introduction

UFC 3-340-01, "Design and Analysis of Hardened Structures to Conventional Weapon Effects," provides the methodologies and criteria to analyze and design a structure so that it can continue to perform its primary mission after a conventional weapon attack (Joint Departments of the Army, Air Force, and Navy and the Defense Special Weapons Agency, 2002) [1]. To achieve this objective, UFC 3-340-01 provides detailed data on weapon characteristics and algorithms for predicting weapon fragmentation and other effects. Due the sensitivity of these data, distribution of the manual is limited to U. S. Government agencies and their contractors.

The requirements in DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," are written "...to manage risks associated with DoD-titled ammunition and explosives (AE) by providing protection criteria to minimize serious injury, loss of life, and damage of property..." from an accidental explosives detonation or other reaction (Office of the Deputy Under Secretary of Defense (Installations and Environment), 2009) [2]. Protection is typically provided by maintaining minimum, default separation distances between each potential explosion site and its

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exposed sites. Specific separation distance requirements are defined in DoD 6055.09-STD and vary with the hazard division of the AE and the level of protection afforded to an exposed site.

In cases where the default separation distance cannot be provided, DoD 6055.09-STD references UFC 3-340-02, “Structures to Resist the Effects of Accidental Explosions,” for design procedures to achieve the required personnel protection, to protect facilities and equipment, and to prevent propagation of explosions (Naval Facilities Engineering Command, U. S. Army Corps of Engineers, Air Force Civil Engineering Support Agency, 2008) [3]. Since its initial publication in 1969 (as Army TM 5-1300/NAVFAC P-397/AFR 88-22), UFC 3-340-02 has been an open distribution document, providing both government and private sector engineers with an invaluable source of blast effects and loading data. The UFC provides detailed procedures for blast load calculation, analysis and design that are illustrated and explained through step-by-step examples in the chapter appendices.

The UFC 3-340-02 protection categories and their corresponding design requirements were developed specifically to satisfy DoD 6055.09-STD explosives safety requirements. These protection categories are summarized in Table 1. As an example, DoD 6055.09-STD, chapter 4 defines personnel protection requirements from higher risk operations. Per section C4.3.1.2, “[W]here required, personnel protection must limit incident blast overpressures to 2.3 psi [15.9 kPa], fragment energies to less than 58 ft-lbs [79 joules], and thermal fluxes to 0.3 calories per square centimeter [12.56 kilowatts per square meter]” (Office of the Deputy Under Secretary of Defense (Installations and Environment), 2009) [2]. UFC 3-340-02 satisfies these personnel protection requirements through application of its Protection Category 1 design requirements.

The primary objective of UFC 4-010-01, “DoD Minimum Antiterrorism Standards for Buildings,” and UFC 4-010-02, “DoD Minimum Antiterrorism Standoff Distances for Buildings,” is “...to minimize the likelihood of mass casualties from terrorist attacks against DoD personnel in the buildings in which they work and live” (Deputy Under Secretary of Defense (Installations and Environment), 2007) [4] [5]. Per UFC 4-010-01, section 2-2, “[T]he overarching philosophy upon which the UFC is based is that comprehensive protection against the range of possible threats may be cost prohibitive, but that an appropriate level of protection can be provided for all DoD personnel at reasonable cost” (Deputy Under Secretary of Defense (Installations and Environment), 2007) [4]. Accordingly, antiterrorism (AT) design guidance focuses on enhancing the blast resistance of typical, conventional construction.

UFC 4-010-01 defines four levels of AT protection for new and existing buildings. These protection levels are summarized in Table 2 and range from very low to high. Similar to DoD 6055.09-STD, UFC 4-010-02 provides data on the minimum separation distances from an explosive donor to various acceptor structures, but unlike DoD 6055-09-STD, these distances consider only an external event and are FOUO.

For cases where the minimum UFC 4-010-02 distances cannot be satisfied, the US Army Corps of Engineers Protective Design Center (PDC) has developed various tools to assist designers in evaluating and designing structures to provide AT protection. The Component Explosive Damage Assessment Workbook (CEDAW) “...generates pressure-impulse (P-i) diagrams and charge weight standoff graphs that are used to determine component damage levels established

by the US Department of Defense (DoD) to an input structural component loaded by blast from an input equivalent TNT charge weight and standoff. CEDAW is intended for generalized first-cut type damage assessments and it predicts response in terms of relatively general, qualitative damage level levels. The approximate approach in CEDAW allows it to calculate very rapid results, which is necessary for many first-cut type damage assessments that must assess a large number of buildings in a short time” (U. S. Army Corps of Engineers Protective Design Center, 2008) [6].

In conjunction with the development of its CEDAW computer code, PDC established flexural response limits corresponding to the four levels of protection defined in UFC 4-010-01. Since these protection levels are intended for application in designing facilities to resist terrorist attack, they consider a wide range of conventional building materials. The AT response limits will be published in an ASCE Blast Standard, currently under final development and slated for release for open comment later this year.

PDC TR-06-01, Rev. 1, “Methodology Manual for the Single-Degree-of-Freedom Blast Effects Design Spreadsheets,” outlines the basis of the SBEDS computer spreadsheets that PDC specifically developed “...as a tool for designers to use in satisfying the Department of Defense (DoD) antiterrorism standards” (U. S. Army Corps of Engineers Protective Design Center, 2008) [7]. Since AT structures may be conventional construction, SBEDS considers a wide range of materials including corrugated metal panel, steel plate, steel beam or beam column, open-web steel joist, reinforced concrete slab, reinforced concrete beam or beam-column, reinforced masonry, wood panel and wood beam or beam-column. The spreadsheets also allow a user to perform single-degree-of-freedom (SDOF) analyses on other materials using a resistance deflection function that is developed and input by the user (U. S. Army Corps of Engineers Protective Design Center, 2005) [8].

### ***Comparison of SBEDS and UFC 3-340-02 Methodologies***

In general, while the analysis and design procedures in SBEDS are based upon UFC 3-340-02, the spreadsheets incorporate numerous changes to the blast load calculation procedures, SDOF analytical models, and design requirements to better match AT test data and exposures. Brief summaries of the more significant differences are provided in the following sections.

#### **Load Prediction**

PDC TR-06-01, Rev. 1, section 2-6.2 provides “an empirical equation for steel cased charges that determines an equivalent bare charge mass,  $W'$ , that can be multiplied by any applicable equivalency factors and used to predict blast load parameters” (U. S. Army Corps of Engineers Protective Design Center, 2008) [7]. This approach allows designers to design structural elements to withstand blast overpressure and impulse only. In comparison, since casing fragments may place additional loads on a structural element and may also degrade its resistance, UFC 3-340-02 does not recognize this reduction in a munition’s net explosive weight. In addition, UFC 3-340-02, section 1-7 recommends the application of a 20% safety factor on the TNT equivalent charge weight to account for unexpected shock wave reflections, construction

methods, quality of construction materials, etc. This increased charge weight is the “effective charge weight” to be used for design (Naval Facilities Engineering Command, U. S. Army Corps of Engineers, Air Force Civil Engineering Support Agency, 2008) [3].

Since the SBEDS computer code was developed primarily to analyze and design structural elements to resist external blast loads, PDC TR-06-01 does not provide load prediction guidance for internal blast events. Per section 2-7 of this document, “[D]etailed coverage of methods to determine confined blast loads is outside the scope of this manual. This discussion is provided in UFC 3-340-01, TM 5-1300, and DOE/TIC 11628 [sic]” (U. S. Army Corps of Engineers Protective Design Center, 2008) [7].

### **Single Degree of Freedom Analytical Model**

SBEDS applies different assumptions in calculating an element’s ultimate resistance. For example, for two-way elements, “[U]ltimate resistance,  $r_u$ , values for members with fixed supports (Cases 2 through 5) have been reduced by 10 percent to account for a more detailed yield line configuration (fan pattern) near corners” (U. S. Army Corps of Engineers Protective Design Center, 2008) [7]. SBEDS also permits consideration of more complex resistance-deflection functions and allows designers to use dynamic reaction forces from a supported component, such as a beam, as the applied load on a supporting component, such as a girder.

### **Design and Detailing of Reinforced Concrete Walls and Slabs**

UFC 3-340-02’s requirements for diagonal tension reinforcement differ substantially from SBEDS, particularly at the close-in design range typical of an internal detonation. UFC 3-340-02 defines three types of single leg stirrups for use as diagonal tension reinforcement. Minimum bar bend requirements for these stirrups vary and are determined based upon the scaled charge standoff distance, the element’s response limit and its spall potential. Type A stirrups have a 90 degree hook on one end and a 135 degree hook on the other end, Type B stirrups have a 135 degree hook on each end, and Type C stirrups have a 180 degree hook on each end. UFC 3-340-02 also places limits on the spacing of stirrups, requires at least one stirrup at each bar intersection and, at close-in charge standoff distances, requires a minimum stirrup area. In comparison, SBEDS “calculates the required area of shear reinforcing steel so that the sum of the concrete and steel shear strengths is equal to the equivalent reaction forces.” While the SBEDS methodology report does recommend a limit on stirrup spacing, it allows the use of stirrups with a 135 degree hook on each end for all levels of protection and standoff distances (U. S. Army Corps of Engineers Protective Design Center, 2008) [7].

If the design support rotation of a reinforced concrete element is greater than 2-degrees or if the section (with any support rotation) is in net tension, UFC 3-340-02, section 4-19.2 requires that the ultimate direct shear capacity of the section,  $V_d$ , be taken as zero and that diagonal bars take all direct shear load. As a result of this requirement, UFC 3-340-02 walls and slabs that may be placed in net tension or that are designed for a support rotation greater than 2-degrees typically have fixed supports.

In comparison, SBEDS calculates the direct shear capacity of reinforced concrete components and compares it to the equivalent static reaction at the support. In so doing, "...[A]ll reinforcement crossing the crack plane, except that which is required to resist net tension in the component, is allowed to serve as shear friction shear reinforcement. This includes flexural bars. Usually the flexural steel and concrete provide sufficient direct shear resistance. In cases where they do not, diagonal bars may also be used as shown in figure 5-8." (U. S. Army Corps of Engineers Protective Design Center, 2008) [7]. SBEDS does not calculate the area of these diagonal bars, since it "is rarely needed for components subjected to external blast." Instead, "...[T]he user should refer to chapter 4 of TM 5-1300 (1990)" (U. S. Army Corps of Engineers Protective Design Center, 2008) [7].

PDC TR-06-01, Rev. 1 does not provide guidance on determining the support conditions of a reinforced concrete slab or beam element. Given the much less stringent direct shear requirements in SBEDS, a designer may incorrectly assume a fixed support condition when the actual support provided is only partially fixed. If this error is made, the ultimate resistance of the element will be overstated, increasing the likelihood of an inadequate flexural design. .

## ***Conclusions***

While both the explosives safety and AT design communities typically use SDOF models to analyze and design structural elements, the levels of protection and resulting design requirements for each community differ markedly. While AT protection criteria focus on the prevention of mass casualties, explosive safety criteria are written to provide specific levels of protection to personnel, to property and to ammunition and explosives.

AT design procedures focus heavily upon protecting personnel from the relatively low blast overpressures and impulses of far range, lower NEW, external blast events. In comparison, explosive safety design guidance considers both far range and close-in blast loads; at the far range, UFC 3-340-02 design procedures may be applied to explosive quantities in the order of 500,000 pounds NEW. UFC 3-340-02 also places supplementary design and detailing requirements on internal blast designs where structural elements often must provide the mandated protection while under combined axial tension and flexure.

In light of the AT community's philosophy that an appropriate level of protection can be provided for all DoD personnel at reasonable cost, AT design procedures and requirements often are based upon enhancing the blast resistance of conventional structural elements. In comparison, explosives safety designs are usually "custom designed" and "custom built" to satisfy specific, operational, maximum credible events and their corresponding low charge standoff distances.

Based upon the foregoing, DDESB only allows use of the SBEDS spreadsheets for preliminary flexural design and element sizing. Final protective construction designs for explosives safety applications, including calculation of blast loads and development of SDOF analytical models, must be prepared in accordance with UFC 3-340-02 criteria and requirements.

## ***Recommendations***

At this time, DDESB and the explosives safety community use various limited distribution computer programs, many of which were developed by NAVFAC-ESC in accordance with UFC 3-340-02 criteria, to calculate the design shock and gas pressure loads on internal structural elements and to develop preliminary reinforced concrete and structural steel designs. The status and possible update of these codes were discussed at the February 2010 UFC 3-340-02 Technical Working Group (TWG) meeting. Given SBEDS ease of use, consideration was given to the development of similar, modified spreadsheets incorporating UFC 3-340-02 criteria and requirements. While TWG members agreed that such a tool would be both useful and welcome, its development would require considerable funding and thus, may not be prudent until the UFC is fully updated. In the meantime, the TWG will consider the incorporation of SBEDS analysis and design approaches in UFC 3-340-02, where appropriate.

## ***References***

1. Joint Departments of the Army, Air Force, and Navy and the Defense Special Weapons Agency (2002), *Design and Analysis of Hardened Structures to Conventional Weapon Effects*, UFC 3-340-01, Distribution authorized to U. S. Government Agencies and their contractors.
2. Office of the Deputy Under Secretary of Defense (Installations and Environment) (2009), *DoD Ammunition and Explosives Safety Standards*, DoD 6055.09-STD, Incorporating Change 2.
3. Naval Facilities Engineering Command, U. S. Army Corps of Engineers, Air Force Civil Engineering Support Agency (2008), *Structures to Resist the Effects of Accidental Explosions*, UFC 3-340-02.
4. Deputy Under Secretary of Defense (Installations and Environment) (2007), *DoD Minimum Antiterrorism Standards for Buildings*, UFC 4-010-01, incorporating change 1.
5. Deputy Under Secretary of Defense (Installations and Environment) (2007), *DoD Minimum Antiterrorism Standoff Distances for Buildings*, UFC 4-010-02, incorporating change 1, Distribution authorized to U. S. Government Agencies and their contractors.
6. U. S. Army Corps of Engineers Protective Design Center (2008), "Methodology Manual for Component Explosive Damage Assessment Workbook (CEDAW)," PDC TR-08-07, Omaha, NE.
7. U. S. Army Corps of Engineers Protective Design Center (2008), "Methodology Manual for the Single-Degree-of-Freedom Blast Effects Design Spreadsheets (SBEDS)," PDC TR-06-01, Revision 1, Omaha, NE.
8. U. S. Army Corps of Engineers Protective Design Center (2005), "Single-Degree-of-Freedom Blast Effects Design Spreadsheets (SBEDS)," PDC TR-05-01, Omaha, NE.

| <b>Protection Category</b> | <b>Description</b>   |
|----------------------------|--|
| 1                          | Protect personnel against the uncontrolled release of hazardous materials, including toxic chemicals, active radiological and/or biological materials; attenuate blast pressure and structural motion to a level consistent with personnel tolerances; and shield personnel from primary and secondary fragments and falling portions of the structure and/or equipment. |
| 2                          | Protect equipment, supplies and stored explosives from fragment impact, blast pressures and structural response.   |
| 3                          | Prevent communication of detonation by fragments, high-blast pressures, and structural response.   |
| 4                          | Prevent mass detonation of explosives as a result of subsequent detonations produced by communication of detonation between two adjoining areas and/or structures. This category is similar to Category 3 except that a controlled communication of detonation is permitted between defined areas.   |

Table 1 – UFC 3-340-02 explosives safety protection categories.



| <b>Level of Protection</b>  | <b>Potential Building Damage/ Performance<sup>2</sup></b>  | <b>Potential Door and Glazing Hazards<sup>3</sup></b>  | <b>Potential Injury</b>  |
|---|--|--|--|
| <b>Below AT Standards<sup>1</sup></b>   | Severe damage. Progressive collapse likely. Space in and around damaged area will be unusable.   | Doors and windows will fail catastrophically and result in lethal hazards. (High hazard rating)  | Majority of personnel in collapse region suffer fatalities. Potential fatalities in areas outside of collapse likely.  |
| <b>Very Low</b>   | Heavy damage – Onset of structural collapse is unlikely. Space in and around damaged area will be unusable.  | Glazing will fracture, come out of the frame, and is likely to be propelled into the building, with the potential to cause serious injuries. (Low hazard rating) Doors may be propelled into rooms, presenting serious hazards.                    | Majority of personnel in damaged area suffer serious injuries with potential for fatalities. Personnel in areas outside damaged area will experience minor to moderate injuries.   |
| <b>Low</b>  | Moderate damage – Building damage will not be economically repairable. Progressive collapse will not occur. Space in and around damaged area will be unusable. | Glazing will fracture, potentially come out of the frame, but at a reduced velocity, does not present a significant injury hazard. (Very low hazard rating) Doors may fail, but they will rebound out of their frames, presenting minimal hazards. | Majority of personnel in damaged area suffer minor to moderate injuries with the potential for a few serious injuries, but fatalities are unlikely. Personnel in areas outside damaged areas will potentially experience a minor to moderate injuries [sic]. |
| <b>Medium</b>   | Minor damage – Building damage will be repairable. Space in and around damaged area can be used and will be fully functional after cleanup and repairs.        | Glazing will fracture, remain in the frame and results in a minimal hazard consisting of glass dust and slivers. (Minimal hazard rating) Doors will stay in frames, but will not be reusable.  | Personnel in damaged areas potentially suffer minor to moderate injuries, but fatalities are unlikely. Personnel in areas outside damaged areas will potentially experience superficial injuries.  |
| <b>High</b>   | Minimal damage. No permanent deformations. The facility will be immediately operable.  | Glazing will not break. (No hazard rating) Doors will be reusable.   | Only superficial injuries are likely.  |
| Notes:<br>1. This is not a level of protection, and should never be a design goal. It only defines a realm of more severe structural response, and may provide useful information in some cases.<br>2. For damage/performance descriptions for primary, secondary and non-structural members, refer to UFC 4-020-02, DoD Security Engineering Facilities Design Manual.<br>3. Glazing hazard levels are from ASTM F 1642. |  |  |  |

Table 2 – UFC 4-010-01 AT levels of protection for new and existing buildings.



# **Comparison of US Blast Design Guidance Documents**



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# Presentation Outline



- Introduction to primary US Department of Defense (DoD) blast design documents
- Comparison of antiterrorism (AT) and explosives safety criteria
  - Protection categories
  - Design requirements
- Conclusions
- Recommendations



# DoD Blast Design Documents



- UFC 3-340-01, “*Design and Analysis of Hardened Structures to Conventional Weapon Effects*,” 1 June 2002.
  - Formerly Army TM 5-855-1/AFPAM 32-1147(I)/NAVFAC P-1080/DAHSCWEMAN-97.
  - Objective: Provide the methodologies and criteria to analyze and design a structure so that it can continue to perform its primary mission after a conventional weapon attack.
  - Oriented toward engineers with a working knowledge in weapons effects, structural dynamics, and the design of hardened, protective structures.
  - Includes detailed data on weapon characteristics and algorithms for predicting weapon fragmentation and other effects.
  - Due to sensitivity of data, distribution limited to U. S. Government agencies and their contractors.



# DoD Blast Design Documents



- UFC 3-340-02, “*Structures to Resist the Effects of Accidental Explosions*,” 5 December 2008.
  - First published in 1969 as Army TM 5-1300/NAVFAC P-397/AFR 88-22; unlimited distribution.
  - Objective: In accordance with DoD 6055.09-STD requirements, provide procedures to achieve personnel protection, to protect facilities and equipment, and to prevent propagation of accidental explosions.
  - Apply when DoD 6055.09-STD’s minimum separation distances cannot be satisfied.
  - Used throughout the world to design blast resistant government, commercial and industrial structures.
  - Specifically written to facilitate use by first-time blast designers.
  - Step-by-step examples in chapter appendices include references to applicable equations, figures and tables.





# DoD Blast Design Documents



- UFC 4-010-01, “*DoD Minimum Antiterrorism Standards for Buildings*,” 22 January 2007 (unlimited distribution) and UFC 4-010-02, “*DoD Minimum Antiterrorism Standoff Distances for Buildings*,” 19 January 2007 (distribution limited to U. S. Government agencies and their contractors).
  - UFC 4-010-01 Objective: Minimize the likelihood of mass casualties from terrorist attacks against DoD personnel in the buildings in which they work and live.
  - UFC 4-010-01 Overarching Philosophy: While comprehensive protection against the range of possible threats may be cost prohibitive, an appropriate level of protection can be provided for all DoD personnel at reasonable cost.



# DoD Blast Design Documents



- Antiterrorism (AT) structural evaluation and blast design guidance are provided primarily through the methodology manuals for two US Army Corps of Engineers, Protective Design Center (Omaha District) spreadsheets.
  - PDC TR 08-07, "*Methodology Manual for Component Explosive Damage Assessment Workbook (CEDAW)*," September 2008 (unlimited distribution).
    - ✓ Generates pressure-impulse (P-i) diagrams and charge weight standoff graphs that are used to determine component damage levels established by DoD to an input structural component loaded by the external blast from an input equivalent TNT charge weight and standoff.
    - ✓ Intended for generalized first-cut type damage assessments; predicts response in terms of relatively general, qualitative damage level levels.



# DoD Blast Design Documents



- ✓ CEDAW's approximate approach allows it to calculate very rapid results, which is necessary for many first-cut type damage assessments that must assess a large number of buildings in a short time.
- PDC-TR-06-01, revision 1, "*Methodology Manual for the Single-Degree-of-Freedom Blast Effects Design Spreadsheets (SBEDS)*," September 2008 (unlimited distribution).
  - ✓ Developed as a tool for designers to use in satisfying the DoD AT standards.





# DoD Blast Design Documents



- ✓ Intended for use by structural engineers with some experience in structural dynamics and blast effects.
- ✓ Since the design of AT structures often is based upon conventional construction, SBEDS considers a wide range of materials including corrugated metal panel, steel plate, steel beam or beam column, open-web steel joist, reinforced concrete slab, reinforced concrete beam or beam-column, reinforced masonry, wood panel and wood beam or beam-column.
- ✓ SBEDS also allows a user to perform single-degree-of-freedom (SDOF) analyses on other materials using a resistance deflection function that is developed and input by the user.



# DoD Protection Categories



- Explosives Safety (UFC 3-340-02)
  - Protection Category 1 – Protect personnel. Per DoD 6055.09-STD, following exposure limits apply:
    - ✓ Incident blast overpressure  $\leq 2.3$  psi [15.9 kPa].
    - ✓ Fragment energy  $\leq 58$  ft-lbs [79 joules]
    - ✓ Thermal flux  $\leq 0.3$  calories per square centimeter [12.56 kilowatts per square meter].
  - Protection Category 2 – Protect equipment, supplies and stored explosives.
  - Protection Category 3 – Prevent communication of detonation.
  - Protection Category 4 – Prevent mass detonation of explosives.



# DoD Protection Categories



- AT (UFC 4-010-01)
  - High - Minimal damage
    - ✓ No permanent deformations. The facility will be immediately operable.
    - ✓ Only superficial injuries are likely.
  - Medium – Minor damage
    - ✓ Building damage will be repairable. Space in and around damaged area can be used and will be fully functional after cleanup and repairs.
    - ✓ Personnel in damaged areas potentially suffer minor to moderate injuries, but fatalities are unlikely. Personnel in areas outside damaged areas will potentially experience superficial injuries.



# DoD Protection Categories



- AT (UFC 4-010-01)
  - Low – Moderate damage
    - ✓ Building damage will not be economically repairable. Progressive collapse will not occur. Space in and around damaged area will be unusable.
    - ✓ Majority of personnel in damaged area suffer minor to moderate injuries with the potential for a few serious injuries, but fatalities are unlikely. Personnel in areas outside damaged areas will potentially experience minor to moderate injuries.



# DoD Protection Categories



- AT (UFC 4-010-01)
  - Very Low – Heavy damage
    - ✓ Onset of structural collapse is unlikely. Space in and around damaged area will be unusable.
    - ✓ Majority of personnel in damaged area suffer serious injuries with potential for fatalities. Personnel in areas outside damaged area will experience minor to moderate injuries.
- AT response limits will be published in an ASCE Blast Standard, currently under final development and slated for release for open comment later this year.





# DoD Blast Design Criteria



- External Blast Load Calculation
  - AT: Per PDC TR-06-01, rev. 1, section 2-6.2, SBEDS allows use of “an empirical equation for steel cased charges that determines an equivalent bare charge mass,  $W'$ , that can be multiplied by any applicable equivalency factors and used to predict blast load parameters.”
  - UFC 3-340-02: Since casing fragments may place additional loads on a structural element and may also degrade its resistance, UFC 3-340-02 does not recognize a NEW reduction for steel case munitions; UFC also applies 20% safety factor on NEW for unexpected shock wave reflections, construction methods, quality of construction materials, etc.



# DoD Blast Design Criteria



- Internal Blast Load Calculation
  - PDC TR-06-01, rev. 1 does not provide load prediction guidance for internal blast events. Per section 2-7, "...[D]etailed coverage of methods to determine confined blast loads is outside the scope of this manual. This discussion is provided in UFC 3-340-01, TM 5-1300, and DOE/TIC 11628 [sic]."
  - UFC 3-340-02 provides extensive guidance for calculating internal shock and gas pressure loads. SHOCK and FRANG codes, developed by NAVFAC-ESC, in accordance with UFC 3-340-02 methodologies.



# DoD Blast Design Criteria



- SDOF Analytical Modeling: In some cases, SBEDS and UFC 3-340-02 apply different assumptions in calculating an element's ultimate resistance.
  - Per PDC TR-06-01, rev. 1, “[U]ltimate resistance,  $r_u$ , values for [two-way] members with fixed supports (Cases 2 through 5) have been reduced by 10 percent to account for a more detailed yield line configuration (fan pattern) near corners.”
  - SBEDS also permits consideration of more complex resistance-deflection functions and allows designers to use dynamic reaction forces from a supported component, such as a beam, as the applied load on a supporting component, such as a girder.





# DoD Blast Design Criteria



- Design and Detailing of Reinforced Concrete Walls and Slabs - Diagonal Tension Reinforcement
  - UFC 3-340-02
    - ✓ Defines three types of single leg stirrups - Minimum bar bend requirements vary from 90-135 degrees to 180-180 degrees; determined based upon the scaled charge standoff distance, the element's response limit and its spall potential.
    - ✓ Places limits on the spacing of stirrups.
    - ✓ Requires at least one stirrup at each bar intersection.
    - ✓ At close-in charge standoff distances, requires a minimum stirrup area.



# DoD Blast Design Criteria



- Design and Detailing of Reinforced Concrete Walls and Slabs - Diagonal Tension Reinforcement
  - Per PDC TR 06-01, rev. 1, SBEDS “calculates the required area of shear reinforcing steel so that the sum of the concrete and steel shear strengths is equal to the equivalent reaction forces” (unlike UFC 3-340-02, there is no minimum stirrup requirement at the close-in design range).
  - Similar to UFC 3-340-02, recommends a limit on stirrup spacing.
  - Allows the use of 135-135 degree single leg stirrups for all levels of protection and standoff distances.



# DoD Blast Design Criteria



- Design and Detailing of Reinforced Concrete Walls and Slabs – Direct Shear
  - UFC 3-340-02 requires that the ultimate direct shear capacity of the concrete section,  $V_d$ , be taken as zero and that diagonal bars take all direct shear load if
    - ✓ Design support rotation is greater than 2-degrees or
    - ✓ The section (with any support rotation) is in net tension.
  - As a result, UFC 3-340-02 elements designed for a support rotation greater than 2-degrees typically have fixed supports.



# DoD Blast Design Criteria



- Design and Detailing of Reinforced Concrete Walls and Slabs – Direct Shear
  - Per PDC TR-06-01, rev. 1, SBEDS calculates the direct shear capacity of reinforced concrete components and compares it to the equivalent static reaction at the support. In so doing, “....[A]ll reinforcement crossing the crack plane, except that which is required to resist net tension in the component, is allowed to serve as shear friction shear reinforcement. This includes flexural bars.”
  - SBEDS does not calculate the area of diagonal bars, since it “is rarely needed for components subjected to external blast.” Instead, “...[T]he user should refer to chapter 4 of TM 5-1300 (1990).”



# Conclusions



- While both the explosives safety and AT design communities typically use SDOF models to analyze and design structural elements, the levels of protection and resulting design requirements for each community differ markedly. While AT protection criteria focus on the prevention of mass casualties, explosives safety criteria are written to provide specific levels of protection to personnel, to property, and to ammunition and explosives.
- AT design procedures focus heavily upon protecting personnel from the relatively low overpressures and impulses of far range, lower NEW, external blast events. In comparison, explosives safety design guidance considers close-in blast loads and places detailed requirements on internal blast designs where structural elements often must provide the mandated protection while under combined axial tension and flexure loads.





# Conclusions



- In light of the AT community's philosophy that an appropriate level of protection can be provided for all DoD personnel at reasonable cost, AT design procedures and requirements often are based upon enhancing the blast resistance of conventional structural elements. In comparison, explosives safety designs are usually "custom designed" and "custom built" to satisfy specific, operational, maximum credible events and their corresponding low charge standoff distances.
- Based upon the foregoing, DDESB only allows use of the SBEDS spreadsheets for preliminary flexural design and element sizing. Final protective construction designs for explosives safety applications, including calculation of blast loads and development of SDOF analytical models, must be prepared in accordance with UFC 3-340-02 criteria and requirements.



# Recommendations



- At this time, DDESB and the explosives safety community use various limited distribution computer programs, many of which were developed by NAVFAC-ESC in accordance with UFC 3-340-02 criteria, to calculate the design shock and gas pressure loads on internal structural elements and to develop preliminary reinforced concrete and structural steel designs. The status and possible update of these codes were discussed at the February 2010 UFC 3-340-02 Technical Working Group (TWG) meeting. Given SBEDS ease of use, consideration was given to the development of similar, modified spreadsheets incorporating UFC 3-340-02 criteria and requirements. While TWG members agreed that such a tool would be both useful and welcome, its development would require considerable funding and thus, may not be prudent until the UFC is fully updated.
- In the meantime, the TWG will consider the incorporation of SBEDS analysis and design approaches in UFC 3-340-02, where appropriate.